Indian J. Phys. **71A** (3), 251–257 (1997)

IJP A
— an international journal

Photon Counting Technique and its Applications in Luminescence Studies

G. S. Mahapatra
Department of Physics, University of Calcutta,
92 Acharya Prafulla Chandra Road, Calcutta 700 009,
India.

Abstract : The photon counting technique, now a days, is emerging as important and popular in the field of studies like feeble light detection, measurement of life times of excited state of the atoms, light yield in different luminescences, dosimetric applications, etc. This technique utilises the single photon responses by a photomultiplier tube and then it counts and detects photons emitted during a radiative emission of some suitable phosphors during their de-excitation.

Keywords : photon counting, decay time, light yield

PACS nos. : 78.60.Ya, 85.60.Ha

1. Introduction

The photon counting technique (PCT) has been found to be very successful in measuring of low level light intensity. This technique can be employed to measure the light having the intensity as feeble as that produced by a single photon [1]. Using this technique the photons emitted from a source can be detected and counted one by one by making a prudent use of a suitable light detector such as a low noise photomultiplier tube (PMT) but without any embelishment in the associated electronics. A number of recent reports on measurements employing PCT demonstrate the wide range of applications to which it can be put [2]. The importance of single photon counting technique lies in the fa-

© 1997 IACS

ct that for a successful measurement of life time, it is essential to count the photons one by one as they are emitted during de-excitation. When light yield measurement during a radiative process is required PCT again can be suitably applied with an appropriate data acquisition system [3,4]. Besides facilitating precise measurement of light intensity PCT hardly finds another even equally reliable competitor in the field of luminescence decay time measurements. We have empolyed this technique in the study of lyoluminescence (LL), a process of light emission from some previously irradiated materials during dissolution in suitable solvents, and related phenomena. Studies on the mass dependence of LL decay times in mannose, a monosaccharide, by employing PCT is reported below.

2. Experiments

The principle of the process of single photon counting by a low noise PMT is described below. As soon as an optical photon of wavelength that corresponds to the wavelength response band of the PMT is incident on the PMT window, i.e., the photocathode, one photoelectron is released from its thin semitransparent surface decided by the quantum efficiency of the photocathode. This photo-electron which travelling down the successive dynodes, results in multiplication in number and finally gives rise to a large burst of electrons which are collected by the anode. The number of these electrons is nearly equal to G, where G is the current gain of the PMT at the anode (in our case it is $\sim 3X10^5$). This burst constitutes a current pulse of very short duration, about a few nanoseconds, and contains a charge eG, where e is the electronic charge. The stray capacitance present at the anode is then charged by this current pulse to generate a voltage pulse ($\sim$ 15 mV for stray capacitance around 10 pF). After a suitably low noise amplification with the help of an active filter amplifier, a multichannel analyser (MCA) is used to record the final pulse height distribution spectrum. In Figure 1 a typical peaked spectrum is shown which illustrates the *single photon response* (SPR) of the PMT . In the same figure the noise pulse height distribution of the PMT is also presented. The noise

response which essentially resembles the SPR is drawn by recording the pulse height distribution in the same PMT placed in complete darkness.

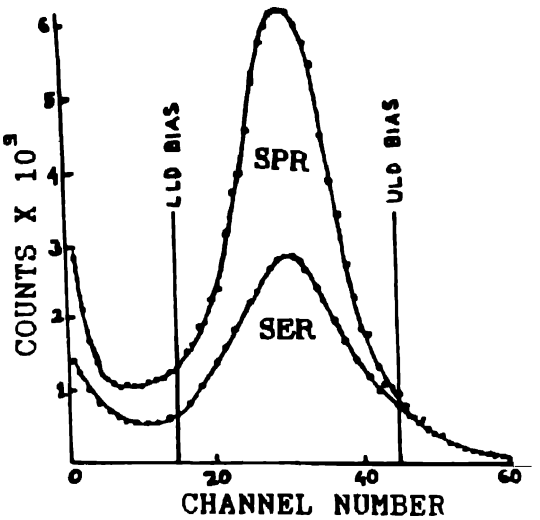

Figure 1. A typical single photon peak recorded during dissolution of 5mg of mannose (dose 1kGy) along with the noise spectrum (SER) and the window settings.

It is interesting to note that the noise spectrum also gives the peak at the same place, i.e., at the same channel number. This noise spectrum is called *single electron response* (SER) which has its origin in the PMT. The photocathode emits thermal electrons which constitute $\sim$ 80% of the total noise output of the PMT. These thermal electrons are mostly emitted singly [3]. Therefore, it may be said that both the SER and SPR spectra are generated from single electrons originating from the photocathode of the PMT through thermal emission in the case of SER and photoelectric emission in case the of SPR. It is then clear that the peaked response after the subtraction of the PMT noise channel by channel gives the resultant shape of the SPR.

The photon counter has been set up using a Hamamatsu R1307 PMT with necessary electronics (PMT supply voltage 1200 V) as shown in Figure 2. The wavelength response of this PMT is 300 - 650 nm with

the peak at 420 nm. It has a dark current of typically 2 nA at a gain 3 X 10^5 and luminous sensitivity of $\sim$ 30 A/lumen. The response of the PMT matches well with the wavelength band of emission of the lyoluminophors used, *viz.*, alkali halides, saccharides, amino acids, enz-

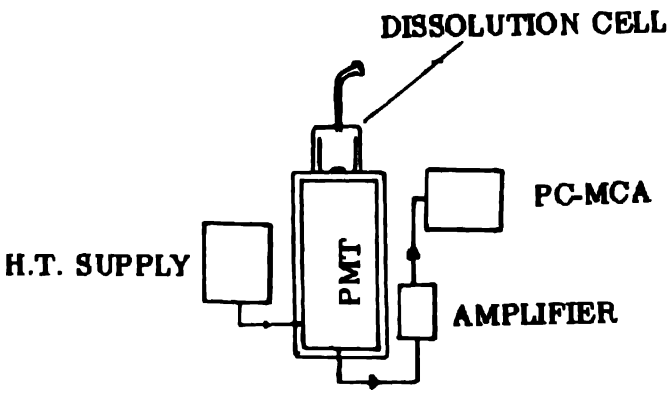

Figure 2. Simplified block diagram of LL reader.

ymes etc. These LL phosphors are prepared exposing them to ionising radiations (in our case γ-rays) to a suitable dose for the generation of active LL centres and then allowed to dissolve in distilled water. In the course of dissolution the active LL centres decay down through some radiative and non-radiative reactions. As soon as the radiative reactions start, emission of light commences. This light is allowed to fall on the PMT window. The PMT output, after proper amplification is fed to a single channel analyser where setting of the biases allow only the pulse height which belong to single photon events. A typical selection of pulse height has been marked by the vertical lines in Figure 1. The lower level discriminator bias setting ensures rejection of the too many smaller PMT dark pulses whereas the upper level discriminator bias setting excludes the few larger pulses beyond the single photon peak. Thus, these settings permit one to acquire data corresponding to single photon events only thereby enabling one to measure decay times. The area under the decay spectrum gives the integrated light yield.

3. Results on Mannose

Since the saccharides are tissue-equivalent, LL measurements with them should serve as a good dosimetric technique. However, the mechanism responsible for LL emission is still not fully understood. To develop this technique for dosimetry, various aspects of LL need to be studied thoroughly. Decay time measurement and its mass dependence which have not been reported earlier are good objects of studies for understanding LL. Accordingly, we have measured, for the first time,

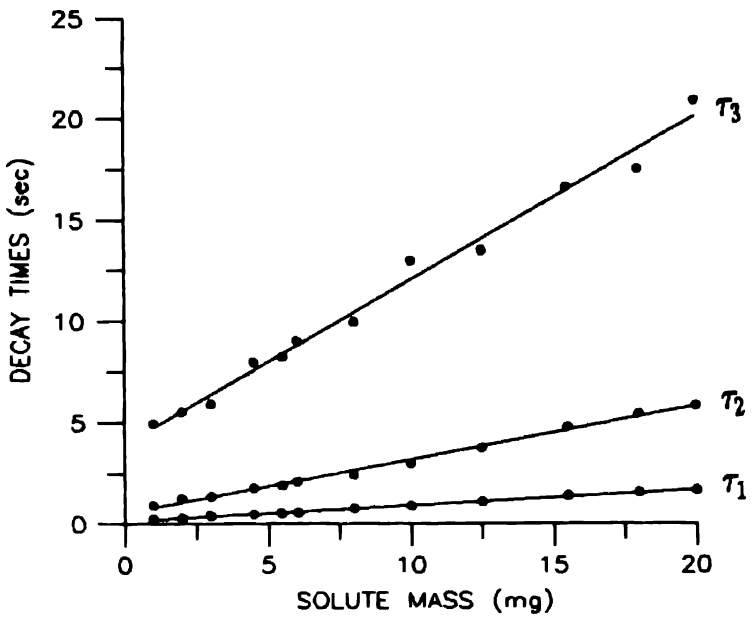

Figure 3. The variation of decay times with solute mass when dissloved in water of pH 6.8 for mannose. Curves marked τ_1, τ_2 and τ_3 are of first, second and third components respectively.

this mass dependence and for the purpose have employed PCT to which no alternative exists for performing decay time measurements [5]. We have taken up the case of mannose because mannose has been found to have largest yield amongst all saccharides. The decay time measurement is done by choosing only the single photon as marked in Figure

1 and recording them in an MCA operated in the multichannel scaling mode with a dwell time of 40 ms per channel. Such a record enables direct determination of decay times [6]. The mass dependence is studied by measuring the decay times for various masses of the solute ranging from 2 mg - 20 mg. The water of pH 6.8 has been used as the solvent.

The findings, presented graphically in Figure 3, show that, for all masses, there are three components of decay. It is seen from Figure 3 that all the three components show mass dependence. The fastest component (τ_1) is affected least whereas the longest component (τ_3) most. The mass dependence of decay times indicates that the radiative reactions, particularly for τ_3, linger as the solute mass increases. The reaction mechanisms which have been attributed to the origins of the three components have been suggested earlier [6]. The reason for mass dependence is still not clear but it is not unlikely that increase in solute mass (*i.e.*, presence of larger number of LL centres) will lengthen the decay times. Since the reactions corresponding to τ_1 and τ_2 are known to be inhibited due to presence of larger mass in the solution because of the competition amongst the increased active LL centres.

Acknowledgements

The author wish to thank to Prof. R. Bhattacharya, Dr. D. Banerjee, Dr. P. Banerji and Mr. C. Haldar for valuable discussions. Financial assistance from University Grants Commission (UGC), New Delhi, is thankfully acknowledged.

References

[1] M B Das, S Bose and R Bhattacharya *Nucl. Instr. and Meth. A* **242** 156 (1985)

[2] C Haldar, G S Mahapatra, P Banerji, D Banerjee and R Bhattacharya *Appl. Radiat. Isot.* **48** 77 (1996)

[3] K J Puite and K V Ettinger *Int. J. Appl. Radiat. Isot.* **33** 1139 (1982)

[4] P Banerji, H K Kundu, D Banerjee and R Bhattacharya *Appl.*

Radiat. Isot. **45** 899 (1994)

[5] P Banerji, H K Kundu, D Banerjee and R Bhattacharya *J. Lumin.* **62** (1994)

[6] G S Mahapatra, C Haldar, P Banerji, D Banerjee and R Bhattacharya *J. Lumin.* **68** 205 (1996)